Performing Scientific Research

If you want to contribute knowledge to the scientific community by conducting a scientific research project, you need to know the basic steps. There are many steps to doing research beginning with identifying a problem to solve. Thoroughly researching a topic and identifying gaps in knowledge is the best place to start with research. From there, you can design experiments, perform them, gather data, and submit your articles for publication!

I- Planning a Research Project

A- Choose a topic that interests you.

First, you must identify a field of study that you would like to research. At the student level, you will either be assigned a topic during a course or choose a lab that performs research that interests you.

Choose a subject that excites you or that you find yourself drawn to.

Scientific research isn't limited to just subjects like biology, chemistry, and physics. As long as you follow the scientific method to perform your study you are doing research.

B- Identify a problem or research question. The research question will be the main focus of your study. Once you have a chosen a topic that interests you, investigate some of the unanswered questions within that field. The research question should be based in a field that you have some familiarity with. You can have more than one research question for a scientific study.

Do a brief literature search to familiarize yourself with what information is already out there and what unanswered questions there are.

Make sure you have the necessary resources available to you (funding and laboratory equipment) to work on the question.

Talk to professors or other researchers and have them help you identify a question that you could work on.

Many articles will state some of the unanswered questions and speculate on future directions or suggest experiments that will be necessary in the future. Use these as a springboard for your own ideas.

C- Perform a comprehensive literature search. You may have done a brief literature search to help you develop a research question, but now you must really do your homework. Find and read articles in the field related to the problem you've identified. Read the current literature as well as some of the seminal papers that established the field.

It is impossible to read every paper, but when performing research, you want to be an expert on the topic. You also don't want to repeat experiments that have already been done.

The literature search will help you design the experiments and determine the proper experimental conditions to use.

Take detailed notes as you read through the literature. You will likely be writing a paper on this information after your study is complete and this information will be the basis of your introduction

D- Revise the research question. A good research question is clear, specific, refers directly to the problem, and identifies a target group of participants.

After reading the literature more thoroughly, you will likely need to revise your research question to encompass all that you have read.

Using your new knowledge, make your research question or questions more specific.

E- Formulate a hypothesis. A hypothesis is testable generalization or prediction about an observable phenomenon. A hypothesis can describe cause and effect or a relationship between the variables you are studying.

An example of a hypothesis is, "The amount of sunlight a plant receives will affect its growth."

Another example is, "Sugar increases hyperactivity in children."

F- Outline your research plan. The research plan is the roadmap for your studies. When working on a research plan, keep in mind that the final objective is usually publication.

Design your experiments with this in mind. Ask yourself the following questions:

Who or what is the study population? Do you need ethical approvals to work with the necessary subjects?

How will each experiment contribute to the answer to the question you're asking?

How is the data collected? How do you define success in a study?

What type of statistics will you use to analyze the data?

If an experiment will not produce data that you would include in a paper, is it necessary to the understanding of the problem? This is called negative data and can help you view your problem from a different perspective or be used as a reference to revise your experiment.

II- Designing an Experiment

A- Determine the sample size. In order for your experiment to be meaningful, you need to have an experimental sample size large enough to perform statistical analyses on. In order to determine this, you need to know some information about your experimental population and use a power analysis calculator.

To use a power analysis, you need to have an estimate of the effect size, an estimation of the variability within the data (standard deviation), the level of significance (standard convention is $p<0.05$), and power (the rate of false negatives you are willing to accept, generally set at 80%).

Running smaller pilot studies can help you gather the necessary information for a proper power analysis to calculate sample size.

If you don't have the means to do a pilot study, use some rough estimations based on information you have gathered from the literature.

B- Identify all of the necessary solutions and equipment. When designing the experiment you need to know all of the solutions you will need to use and the type of equipment you will need access to. Many universities have core facilities with instruments you can use if your specific lab does not have all of the equipment necessary.

You may need to be trained on the equipment and develop the proper expertise before you can start your experiments. Keep this in mind when planning a timeline.

If you don't have access to the necessary equipment, you might consider working with collaborators who have the equipment and expertise.

C- State all experimental conditions. The key to a well-designed experiment is to have a manageable number of testable conditions. If you are doing a drug study, you probably want to test different dosages, but you don't want too many. You will likely have to do a few smaller experiments to optimize the test conditions you will use in the final experiments.

Literature searches can help you identify time points, dosages, and treatment conditions relevant to your studies.

D- Include the necessary controls. Experimental data is useless without the proper control conditions to compare them to. A control is a condition that is kept constant and used to measure the change of the experimental condition.

When a known response is expected, it's considered a positive control. When no response is expected, it's considered a negative control.

A proper experiment has only one variable and multiple controls to ensure that any changes seen in the results are due specifically to the variable that was changed.

To test different variables, you will need to perform multiple experiments.

E- Define the experimental outcomes. In research you must identify and define what the outcome is for your study. You also want to define what you consider "success" of an experiment. If you are studying a biological process, the outcome may be the measure of the amount of a specific protein produced.

The outcomes must be measurable with consistency or they will not produce usable data.

All statistical analyses to be used for the study should be established before data collection.

F- Write up the experimental protocol. After completing the overall design of the experiment, write up a detailed protocol that includes every condition to be tested and all the necessary calculations. Performing the experiment is much simpler when you have done all of planning before you begin.

The more detailed you make the protocol, the easier it will be to follow and repeat the experiment later.

III- Conducting the Experiments

A- Plan your experiments. In order to complete your studies in a reasonable amount of time, it's helpful to draw up a loose schedule of when you will do each experiment. Keep in mind that many experiments will not work the first time and you will have to repeat them to make sure the data is consistent.

Use a weekly or monthly calendar to schedule experiments, including time for analysis and interpretation of results.

As you continue through experiments, some conditions may change or perhaps you will end up going in a different direction. This is normal, just be flexible with your schedule.

B- Gather the necessary materials. During the design phase, you will have written up a detailed protocol that should include all of the solutions and components needed to perform the experiment. Using this write-up gather everything you will need. Make sure to sign up to use shared equipment in advance so it will be available to you when you need it.

Do as much of the small stuff as possible the day before such as labeling tubes and making solutions.

C- Perform the experiment. The day of the experiment, use your detailed protocol and follow the instructions closely. If you deviate from the written protocol at all, make sure to note what you did that was different. Keeping a lab notebook with all of your experiments and results is essential to conducting research.

The first time you do an experiment, it is extremely likely that you will make mistakes or things will go wrong. This is totally normal. Take notes and learn from your mistakes for the next experiment.

Record your results in your laboratory notebook.

D- Troubleshoot the experiment. If the data you obtained from an experiment indicates that the experiment itself didn't work, you will need to troubleshoot it and figure out what went wrong. There are a number of factors that can contribute to an experiment failing:

If you were using a special kit from a company, contact them or seek out their troubleshooting information.

Make sure all of the reagents used were not past their use-by date.

Check to make sure all of your instruments were working properly that day.

Double check all of your calculations and make sure the proper amounts and solution concentrations were used.

E- Repeat the experiment. Once everything has been optimized and troubleshooted, you will simply need to repeat the experiment until you have the correct number of data samples to analyze as determined before in the design phase. After collecting all of the data, you can analyze it and start drafting a manuscript for publication.

Use all of the same reagents and instruments whenever possible to limit variability between experiments.

IV- Analyzing and Publishing the Data

A- Analyze the raw data. For most experiments you will be given a raw data output of numbers. Depending on the study, you will transfer these numbers into another program to make graphs and compare the various groups. It's important to pay close attention to the data when moving it between programs.

Take care to avoid copying and pasting rows or columns of data incorrectly.

B- Run the proper statistics. During the experimental design phase, you should have decided on the statistical tests and analyses you would perform on the data. Once finished with data collection, run these tests to determine significance within your datasets.

Indicate significance where applicable on all of your figures and state the exact statistical values within the text of the manuscript.

Use programs such as Graphpad Prism, R, and SAS for the analysis.

C- Make publication quality figures. There are many programs used in the scientific community to generate figures that would be fit for publication, but even simple programs such as Excel can be used. Figures should be clear and concise. Make sure all font sizes used are clearly legible in both size and style.

Organize panels so that similar data is grouped together.

Avoid using color within the figures as there are generally expensive fees associated with color figures.

D- Write the paper for publication. When you have all of your results gathered together and in figure form, you can start writing the manuscript. Begin with the material and methods section as this is the easiest. Describe the data in the results section. Talk about what your results mean, how they fit into the field, possible future directions, and remaining gaps in the field in the discussion. Finish with the introduction, abstract, and title.

Determine the journal you want to submit for publication before writing so you can follow their style guide.

E- Submit the manuscript for publication. Follow the submission guidelines and the style guide specific to the journal you submit the manuscript to. They will contact you within a few weeks with comments about the paper. It may be sent back without review or it will be sent to other scientists for reading and comments.

After the paper is reviewed by other knowledgeable professionals in the field, it will come back with comments that you will need to address.

If the paper does not get submitted for review, you will need to submit it to a different journal. This may require revisions to adhere to the new journals style requirements.

F- Revise the manuscript. When you get the manuscript back from peer-review you will have to revise the paper according to the comments. You may need to perform

many more experiments or you may simply need to provide a few more details or do some small easy experiments.

To address the comments, revise the manuscript and write a cover letter rebuttal stating how each comment was taken into account in the revised paper.

G- Resubmit for publication. After final revisions, resubmit the paper to the journal for another review. Usually, this is the final step and the paper will be published; however, it is possible that you may need to do another round of revisions.

Once your manuscript is accepted, you will be sent proofs to review and then it will be ready for publication!